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POLYMERIC SENSORS FOR HEALTH MONITORING OF COMPOSITE STRUCTURES (PREPRINT)

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14. ABSTRACT
Composites are rapidly replacing metals in structural applications due to their ability to outperform metals at significant weight savings. This has resulted in the need for monitoring techniques to prevent catastrophic failures. Crosslink is developing a real-time, light-weight strain/damage sensor system that can be either embedded in or superficially bonded at strategic locations to monitor structural integrity. These sensors utilize inherently conducting polymer (ICP) films. ICP-based sensors do not deteriorate with fatigue and have been shown to possess higher strain sensing capabilities. These are capable of sensing physical stretching and acoustic waves, as well as fluctuations in humidity and temperature. Crosslink is developing modules for wireless transmission of the data to identify the location and extent of damage, along with the prediction capability of the structure's remaining service life.

15. SUBJECT TERMS
strain sensor, acoustic emission sensor, conducting polymer, structural health monitoring, wireless communication

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ABSTRACT

Composites are rapidly replacing metals in structural applications due to their ability to outperform metals at significant weight savings. This has resulted in the need for monitoring techniques to prevent catastrophic failures. Crosslink is developing a real-time, light-weight strain/damage sensor system that can be either embedded in or superficially bonded at strategic locations to monitor structural integrity. These sensors utilize inherently conducting polymer (ICP) films. ICP-based sensors do not deteriorate with fatigue and have been shown to possess higher strain sensing capabilities. These are capable of sensing physical stretching and acoustic waves, as well as fluctuations in humidity and temperature. Crosslink is developing modules for wireless transmission of the data to identify the location and extent of damage, along with the prediction capability of the structure's remaining service life.

Keywords: Strain sensor, Acoustic emission sensor, Conducting polymer, Structural health monitoring, Wireless communication

1. INTRODUCTION

Structural health monitoring (SHM) is a process of implementing a damage sensing strategy that is expected to prevent catastrophic failure by predicting the onset of failure. However, composites may contain invisible microcracks and delaminations, which propagate under load. To date, limited information is available on the mechanisms of ageing and property degradation in the composites. The sensor system must be able to sense repetitive changes and sudden deformations. Several approaches have been proposed to detect strain in "real time" in composite structures such as optical fibers [1], electrical resistance strain gauges [2], acoustic emission [3], and piezoelectric transducers [4]. For any SHM system to be acceptable, it must be able to withstand the rigors of composite manufacturing, if imbedded in the structure, and have non-intrusive connection systems for communication and interrogation. The focus of the current work is to develop a surface mounted sensor system sensitive to strain and acoustic waves. Crosslink has developed a processable polyaniline (PANI) formulation (PAC 1003) whose conductivity can be engineered to fit sensor needs. Films can be applied using methods such as inkjet printing and screen printing. PAC 1003 -based strain and acoustic emission sensors are shown in Fig. 1.

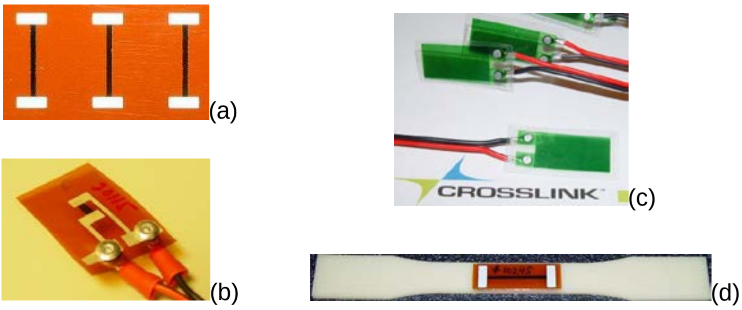


Fig. 1: Crosslink's ICP based sensors: (a) primary strain sensors, (b) modified strain sensors with modified connectivity, (c) acoustic emission sensors, and (d) a strain sensor on a test substrate.

2. SENSOR CHARACTERISTICS

2.1. Strain sensor

Strain sensors were fabricated by screen-printing PAC 1003 on a Kapton® substrate. Silver ink AG 530, obtained from Conducting Compounds, Inc. (Hudson, NH) was used at each end for electrical measurements. In static testing, the strain sensors showed sensitivity up to 150% strain. However, the Kapton® substrate failed. No deterioration in sensitivity was seen after exposing the sensors at 0.5% strain for 10^6 cycles.

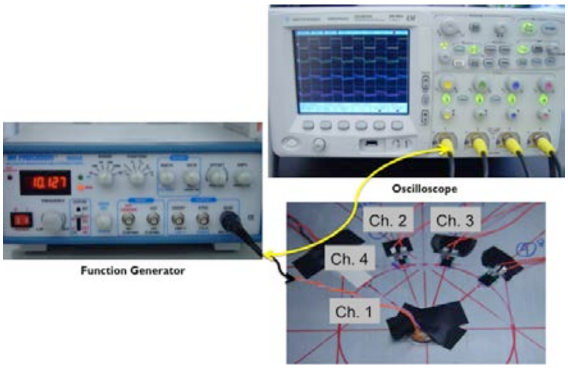
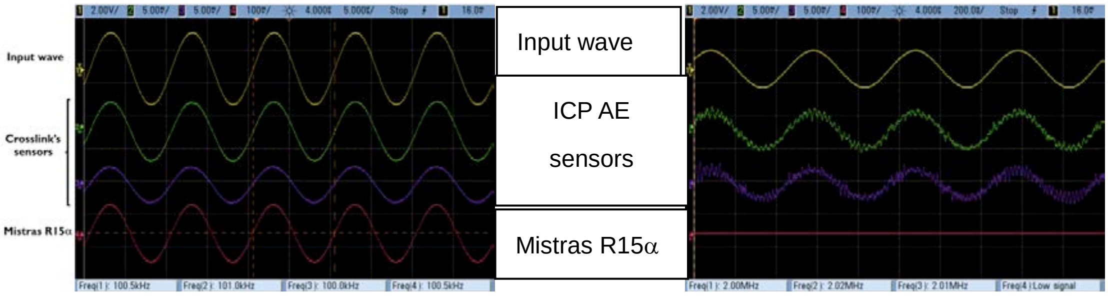


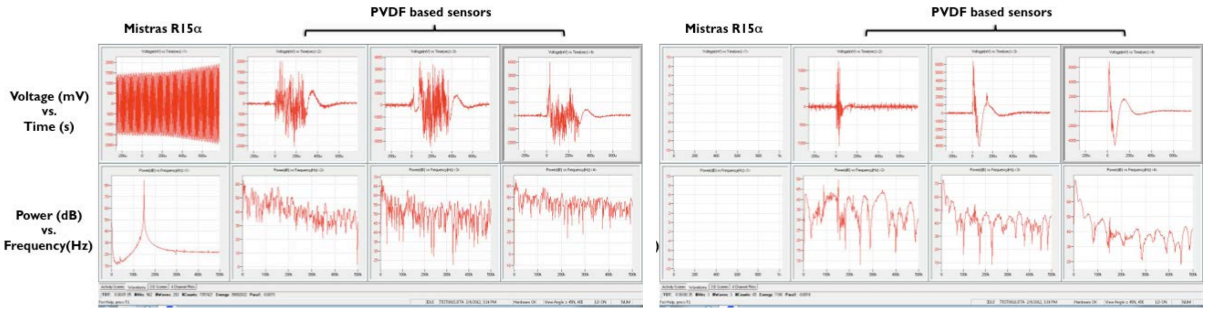
Fig. 2: Complete setup for the AE sensor characterization test. The input wave was directly fed to ch.1 of the oscilloscope and may not represent the actual vibrations generated by the piezo-transducer.

2.2. Acoustic emission (AE) sensor

ICP-based AE sensors were fabricated by printing PAC 1003 on polyvinylidene difluoride (PVDF) sheets obtained from Measurement Specialties, Inc. (Hampton, VA). A wave generator (BK Precision 4003A) was used to generate voltage signals with selectable preset waveforms with controllable frequencies between 4 Hz and 4 MHz. A piezoelectric transducer introduced acoustic waves onto the substrate. The test setup is shown in Fig. 2. Crosslink's sensors responded to signals ranging from 10 Hz to 4 MHz while Mistras' R15α piezoceramic sensor showed much higher signal strength between 100– 300 kHz, but showed minimal to no sensitivity at higher frequencies. The representative responses are shown in Fig. 3.



(a) Response to 100 kHz sine wave (b) response to 2 MHz sine wave



(c) Response to a 150 kHz input wave (d) Response to a 1 MHz input wave

Fig. 3: Comparison of AE sensing characteristics of Crosslink's sensors and Mistras' R15α sensor. Sensors were laid on an aluminum plate as shown in Fig. 2 (in place of ch. 4).

Figures 3(c) and 3(d) shows the AE sensor data. Mistras' sensor has a resonance frequency of 150 kHz and shows continuous wave capture and a high number of hits (not shown). However, the PVDF-ICP based AE sensors pick them as hits as well and show similar responses. The second row in 3c) and 3d represent the power spectrum and confirms the capability of Mistras' sensor at 150 kHz. PVDF-based sensors show several peaks, proving its wide range of applicability. When tested at 1 MHz, only the PVDF-based sensors pick up the signal and represent a unique advantage over piezo-ceramic sensors.

3. WIRELESS MODULE INTEGRATION

Civionics, LLC, (Ann Arbor, MI, USA) developed a wireless data acquisition system (Fig. 4) and an associated graphical user interface (GUI) system. This system abides by the IEEE 802.15.4 protocol and operates in the 2.4GHz band. It is capable of reporting the resistance of up to four strain sensors with accuracy under ±0.05% and supports sampling rates of up to 200Hz. A wireless acquisition system for AE data handling is currently under development.

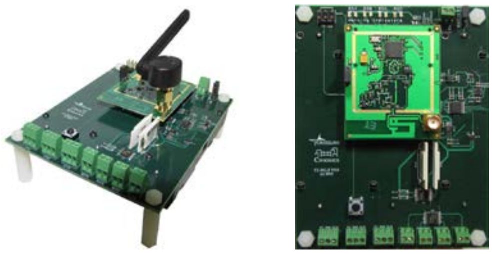


Fig. 4: Wireless sensor node for data acquisition from Crosslink's strain transducers.

4. SUMMARY & CONCLUSIONS

Crosslink has developed ICP-based strain and acoustic emission sensors. The strain sensors can be used to sense material strains up to 150% and do not demonstrate fatigue even after 1 million load cycles at 0.5% strain. ICP-based AE sensors respond to acoustic signals in a wide frequency range (100 kHz – 4 MHz). This enables ICP-based AE sensors to distinguish low frequency impact damage versus a high frequency fiber fracture in a single sensor.

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